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Reducing Emissions from the Wood Furniture Industry with Waterborne Coatings

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This program was initiated to develop meaningful, defensible, and reliable data on emission reduction benefits from the use of reduced hydrocarbon finishes. The program also included assessing add-on emission control options and considering installation aspects such as costs.

This program, based on currently available technology, represents the best efforts of finish suppliers and furniture manufacturers to produce furniture coated with lower hydrocarbon finishes. All major finisn suppliers participated using waterborne or low-solvent finishes rather than other finish technologies (e.g., powders). The participating furniture companies represented the industry in product line, styles, quality, degree of technical and merchandising sophistication, and processing capabilities.

Use of lower hydrocarbon finishes could significantly reduce volatile organic carbon emissions; during this program, reductions of 26 to 94 percent were achieved. However, none of the reduced hydrocarbon finish systems products evaluated were commercially acceptable to the furniture manufacturers because of grain raising, haziness, lack of depth or sheen, and inadequate smoothness and resistance to household chemicals or fingerprinting.

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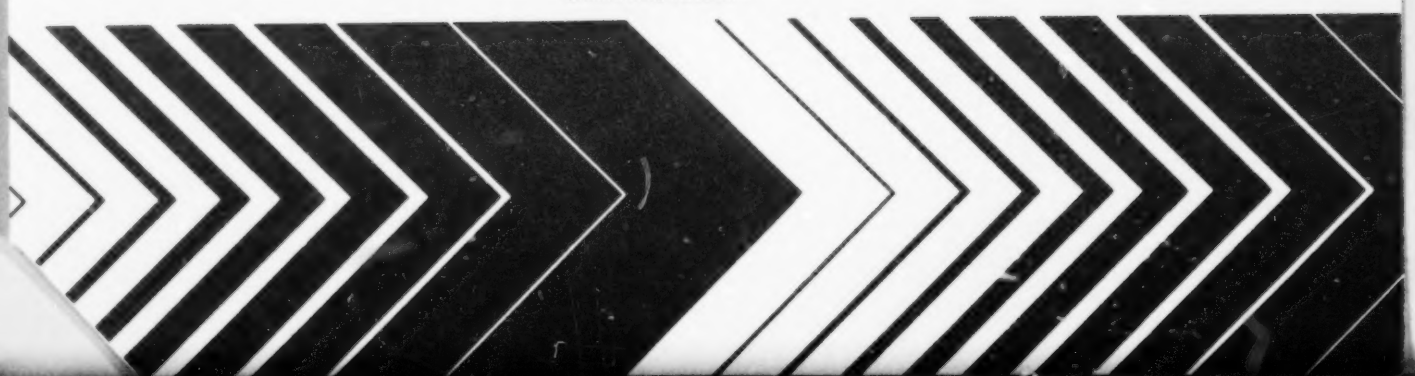

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July 1980

REDUCING EMISSIONS FROM THE WOOD FURNITURE INDUSTRY WITH WATERBORNE COATINGS

by

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Contract 68-03-2584
Tasks 3 and 4

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This document reports on a recently completed project whose purpose was to identify, test, and evaluate lower hydrocarbon finishes for wood furniture. The findings in this report can be used by the Office of Air Quality, Planning and Standards, furniture manufacturers, and finish suppliers to determine whether reasonably available control technology exists on which regulations for wood furniture finishing can be based. The information in this report can also serve as a basis for future work. For further information, contact the Food and Wood Products Branch, IERL-Ci, Ohio.

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ABSTRACT

Through a review of various surface coating technologies including wood furniture, it became apparent that little, if any, progress had been made toward the use of lower hydrocarbon finishes by either finish producers or furniture manufacturers. Some tests had been made with varying results. However, no field applications using lower hydrocarbon finishes on continuous process lines had been successful.

This program was initiated to develop meaningful, defensible, and reliable data on emission reduction benefits from the use of reduced hydrocarbon finishes. Add-on emission control options were assessed, and installation aspects, such as costs, were considered.

This program, based on currently available technology, represents the best efforts of finish suppliers and furniture manufacturers to produce furniture coated with lower hydrocarbon finishes. All major finish suppliers participated using waterborne or low-solvent finishes rather than other finish technologies (e.g., powders). The participating furniture companies represented the industry in product line, styles, quality, degree of technical and merchandising sophisitication, and processing capabilities.

Use of lower hydrocarbon finishes could significantly reduce volatile organic carbon emissions; during this program, reductions of 26 to 94 percent were achieved. However, none of the reduced hydrocarbon finish systems products evaluated were commercially acceptable to the furniture manufacturers because of grain raising, haziness, lack of depth or sheen, and inadequate smoothness and resistance to household chemicals or fingerprinting.

In all cases, major system changes will be required to process reduced hydrocarbon finishes. Major increases in the number of finishing, rubbing, and repair personnel will also be needed unless significant improvements in coating chemistry can be achieved. Add-on emission controls are prohibitively expensive and will be detrimental to the development of new finish technology.

Any decision to change from solvent-borne to reduced hydrocarbon finishes will have to consider a multitude of Federal, state, and local rules and regulations, most of which have not addressed the impact of reduced hydrocarbon finishes.

This report was submitted in fulfillment of Tasks 3 and 4 of Contract 68-03-2584 by Acurex Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period March 25, 1978 to June 15, 1979 and work was completed as of July 20, 1979.

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UNIT CONVERSIONS

To Convert From	to	Multiply by
cubic meters per minute (m^3/min)	cubic feet per minute (cfm)	35.31
dollars per liter ($/l)	dollars per gallon ($/gal)	3.78
kilograms per 100 square meters (kg/100 m^2)	pounds per 1,000 square feet (lb/1,000 ft^2)	2.045
kiloPascal (kPa)	pounds per square inche (psi)	0.145
liter (l)	gallon (gal)	0.265
megagrams (Mg)	tons (T)	1.102
meters (m)	feet (ft)	3.28
normal cubic meters per minute (Nm^3/min)	standard cubic feet per minute (scfm)	35.31
square meters per liter (m^2/l)	square feet per gallon (ft^2/gal)	40.67

Other Unit Conversion

degrees Fahrenheit (^oF) = 1.8 x degrees Celcius (^oC) + 32

SECTION 1

INTRODUCTION

A program to identify, test, and evaluate new finishes for wood furniture was initiated by the U.S. Environmental Protection Agency (EPA) to help the Office of Air Quality, Planning and Standards (OAQPS) define a reasonably available control technology on which to base regulations. OAQPS is responsible for developing hydrocarbon control technique guidelines (CTG). For certain industries, specific control strategies have already been recommended to the states for inclusion in their implementation plans.

Major stationary source emitters of hydrocarbons to the air for which CTG's have already been developed include bulk petroleum storage terminals, first-stage gasoline marketing, and several surface coating operations. Other industries now under study, and for which CTG's will be developed, include miscellaneous metal products, graphic arts, and flatwood finishing. The wood furniture manufacturing industry is one of the industries under review before issuance of draft guidelines documents.

PROGRAM DEVELOPMENT

Through a review of coating technology in 11 surface coating operations including wood furniture finishing, it became apparent that little, if any, progress had been made in the use of lower hydrocarbon finishes by either furniture finish producers or furniture manufacturers. Some trials had been run with varying results, but no field applications of such materials on continuous process lines had been successful.

Therefore, a proposal was made to develop meaningful, defensible, and reliable data on what could be done with reduced hydrocarbon finishes. Acurex Corporation was selected to manage the proposed program and to assess add-on emission control options, as well as to consider aspects of installing the new coating technology such as costs. Booz, Allen and Hamilton, Inc., was subcontracted by Acurex to develop and implement the actual furniture finishing study test runs using the new, lower hydrocarbon finishes.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This program represents the best efforts of finish suppliers and furniture manufacturers based on currently available technology. Participants realized that full cooperation was to the industry's advantage in obtaining realistic data for use in the possible development of regulations. All the major finish suppliers participated using the best materials available to them, and all chose waterborne or low-solvent finishes rather than other reduced solvent finish technologies (e.g., high solids, powders, etc.). The participating furniture companies were representative of the industry in product line, styles, quality, degree of technical and merchandising sophistication, and processing capabilities. Participants were honest, forthright, and constructive in helping the program staff conduct the study and present meaningful results.

Within this framework, it is apparent that significant progress has been made in previous years and, more important, during this program to attempt to develop waterborne or low-solvent finishes with acceptable application and performance characteristics. Use of these finishes could significantly reduce volatile organic carbon (VOC) emissions; the individual finishing trials demonstrated a possible reduction of 26 to 94 percent. However, none of the waterborne or low-solvent finish systems evaluated were commercially acceptable (to the furniture manufacturers) because of grain raising, haziness, lack of depth or sheen, and inadequate smoothness. Furthermore, none of the waterborne systems were as resistant as conventional finishes to household chemicals or printing (loss or transfer of finish materials by direct contact with another object such as a packing carton).

In all cases, major system changes will be required to process waterborne finishes, including replacement or modification of existing storage tanks and internal plumbing, and significant increases in oven capacities (or addition of ovens where none currently exist). Major increases in the number of finishing, rubbing, and repair personnel will be needed unless significant improvements in coating chemistry can be achieved.

Add-on emission controls are prohibitively expensive and their use will be detrimental to the development of new finish technology (waterborne or high solids coatings). Since waterborne and low-solvent finishes appear to be the only currently viable method to reduce VOC emissions, further efforts should be expended by the industry and its suppliers to upgrade these finishes to commercial acceptability.

Any decision on transition from solvent-borne to waterborne finish systems will have to consider the following rules and regulations:

- Toxic Substances Control Act (TSCA)
- Resource Conservation and Recovery Act (RCRA)
- Effluent guidelines limitations
- The health and safety workplace requirements of the Federal Occupational Safety and Health Administraton (OSHA) or similar state agencies
- Consumer Product Safety Commission requirements
- State or local rules or regulations

The impact of TSCA on the introduction of new chemical substances into plant use and the commercial marketplace has not been addressed by OAQPS in the draft guideline currently under consideration for the furniture industry; neither has the introduction of priority or non-conventional pollutants into wastewater treatment systems been addressed. Considering these rules and regulations is outside the scope of this study and will have to be dealt with at some later time. Any regulation being developed should also consider the complexity and style-oriented character of this industry and pace itself accordingly.

RECOMMENDATIONS

Based on this study, it is recommended that efforts continue to develop suitable waterborne or low-solvent finishes for wood furniture to reduce VOC emissions from this industry. In this regard, a large number of waterborne or low-solvent finished pieces should be produced and used to establish long-term performance characteristics. Stripping and repair techniques should also be developed and evaluated to minimize difficulties in the plant, showroom, and home.

When waterborne and low-solvent finishes and repair materials have been developed to the point of commercial acceptability, only then can regulations be recommended for their use equally and without discrimination across the entire industry.

SECTION 3

FURNITURE INDUSTRY

INDUSTRY STRUCTURE

The wood furniture industry is broadly based with many unique characteristics. In 1975, 5,477 firms employing 258,673 persons were engaged in the manufacture of all types of wood furniture. Table 1 organizes the wood furniture industry by SIC code and size. The industry tends to be concentrated in North Carolina, South Carolina, Virginia, and Tennessee.

Wood furniture is classified as cabinetry, household furniture, or institutional furniture. In 1977, shipments of wood household furniture, which includes upholstered furniture and television and radio cabinets, were estimated to have been $6.96 billion; shipments in 1978 for these products were estimated at approximately $7.5 billion. Cabinetry shipments were estimated in 1977 to be approximately $2.16 billion.

FURNITURE AND FINISHING STANDARDS

Wood furniture is generally categorized as high, medium, or low end. Companies often specialize in the production of one of these quality levels. High, medium, and low end furniture account for 10, 30, and 60 percent, respectively, of industry sales. On a unit basis, the percentages are approximately 8, 28, and 64, respectively.

The quality of furniture is closely correlated with the number of finishing operations performed on the piece. A low end piece might undergo from 6 to 12 finishing operations, while a high end piece could require up to 30 finishing operations. A greater percentage of low end furniture will be painted, as opposed to being finished to provide a natural wood grain appearance; plastics, laminated vinyl overlays, and lower quality veneer will customarily be applied to low end furniture using high-speed production techniques. High end furniture, on the other hand, will typically be finished with more topcoats and intermediate handcraft steps than either medium or low end furniture. Table 2 presents a sample wood finishing schedule.

The six SIC code groups also have unique finishing requirements. Finishing practices for exposed wood surfaces are similar for all household wood furniture, including television and other cabinets, regardless of whether or not it is upholstered. Wood office or institutional furniture requires finishes having somewhat more durability than those used for

TABLE 1. WOOD FURNITURE INDUSTRY STRUCTURE

SIC Code	Industry	Typical Products	Number of Establishments[a]				Number of Employees[a]			
			Small	Medium	Large	Total	Small	Medium	Large	Total
2434	Wood kitchen cabinets	Cabinets, to be built-in Cabinets, factory made Vanities, bathroom, and other	1,547	129	10	1,686	13,125	13,366	3,690	30,181
2511	Wood household furniture, except upholstered	Beds, bookcases, buffets, chairs, chests, coffee tables, cradles, cribs, dressers, rockers, secretaries, stools, and tables	1,444	307	116	1,867	17,214	34,649	64,522	116,385
2512	Wood household furniture, upholstered	Chairs, couches, davenports, living room furniture, rockers, and sofas	865	310	59	1,234	14,216	33,441	26,356	74,013
2517	Wood television, radio, phonograph, and sewing machine cabinets	Phonograph cabinets and cases, radio cabinets and cases, sewing machine cabinets and cases, stereo cabinets, and television cabinets	47	17	8	72	589	1,642	5,018	7,249
2521	Wood office furniture	Benches, bookcases, cabinets, chairs, desks, filing boxes, furniture stools, and tables	186	46	9	241	2,605	5,187	3,834	11,626
2531	Public building and related furniture	Benches, blackboards, bleachers, chairs, church furniture, and seats	280	85	12	377	4,221	9,539	5,459	19,219
		TOTAL	4,369	894	214	5,477	51,970	97,824	108,879	258,673

[a]By employment size: small = 1 to 49 employees; medium = 50 to 249 employees; large = 250 or more employees.

Source: County Business Patterns, U.S. Department of Commerce, Bureau of the Census, 1975.

TABLE 2. TYPICAL WOOD FURNITURE FINISHING SCHEDULE

Operation	Time Allowed (minutes)	Number of Persons Per Operation
Load	5	1
Spray uniform stain	1.5	2
Dry	15	
Spray NGR stain	1.5	2
Dry	20	
Spray washcoat	1.5	2
Dry	20	
Sand lightly	1.5	4
Spray filler	1.5	2
Flashoff filler	2	
Wipe filler	4	8
Dry	45	
Spray sealer	1.5	2
Dry	30	
Sand	3	7
Spray sealer	1.5	2
Dry	30	
Sand	3	7
Spray glaze	1.5	2
Wipe and brush	5	13
Dry	60	
Distress	2	4
Spray lacquer	1.5	2
Dry	45	
Spray lacquer	1.5	2
Dry	75	
Unload	5	1
Return to load	15	
Total	399	63

Source: Technical Paper, Society of Manufacturing Engineers, MS75-251.

household furniture. Finally, wood kitchen cabinets, the largest subgroup in wood furniture, have whole finishing systems specifically developed for them.

Approximately 60 to 65 percent of the cabinetry products are finished similarly to wood household furniture, using thermosetting materials with higher solids for greater resistance to greases, oils, and kitchen cleaners. Typically these finishing systems consist of a toner or stain, a sealer, a wiping stain, and a topcoat. Approximately 25 to 30 percent of the cabinets are finished either by painting or applying a decorative high-pressure laminate. Five to 10 percent have vinyl-coated exterior surfaces. Most kitchen cabinetry uses regularly shaped parts cut from flat sheet stock, which is currently finished in flatwood finishing lines. Despite similarities, kitchen cabinetry has exposure requirements significantly different than other household wood furniture, and so its production is treated as a separate industry. The kitchen cabinet industry alone consumes 70 to 75 million dollars worth of finishes per year (approximately 76 to 95 million liters).

CURRENT FURNITURE FINISHES

Suppliers

The following firms are major suppliers of finishes to the wood furniture industry:

- Guardsman Chemicals
- Lilly Company
- Reliance Universal
- Gilbert Spruance
- Inmont Corporation
- Mobil Chemical
- Sherwin Williams

The first three firms supply 60 to 70 percent of the finishes used on wood furniture. All of these firms are developing waterborne and other lower solvent finishing systems.

Solvent Content

The solvent content of wood furniture finishes currently in use ranges from 50 to 97 percent by weight. This content varies according to the required film build and drying characteristics. Finishes are also thinned with solvent to allow proper application. Typical solvents used in wood furniture finishes are alcohols, aliphatics, aromatics, esters, glycol ethers, and ketones.

A variety of finishes are used to provide color, depth, and a smoothly finished appearance. Table 3 outlines typical wood furniture finishes and gives their purpose and solids content. (In this industry, solids content is given on a weight basis.) Finishing materials generally represent from 3 to 7 percent of the furniture selling price.

TABLE 3. COMMONLY USED WOOD FURNITURE FINISHES*

Finish	Purpose	Percent Solids By Weight
Stains (sap, body, shading, padding, spatter)	Gives color uniformity; develops wood grains and character	3 to 5
Washcoat	Seals wood surface; prevents subsequent unwanted staining from penetrating filler coat	6
Wiping stain	Gives color uniformity and texture	40
Filler	Fills large pores in wood	60
Sealer	Seals the wood for application of subsequent coats	15 to 18
Glaze	Penetrates and adheres to sealer	30 to 40
Topcoats	Provides deep, clear, durable final finish	21 to 27

*"Surface Coating in the Wood Furniture Industry," October 20, 1978, Foster D. Snell Division, Booz, Allen and Hamilton Inc., Florham Park, New Jersey.

Emissions Levels

An estimated 630 to 680 Mg of organic solvents are emitted per day through all types of wood furniture finishing operations. Roughly 540 Mg per day are emitted through the finishing of conventional wood furniture. Another 90 to 140 Mg of volatile organics are emitted through the finishing of kitchen cabinets and other SIC 2434 products.

Roughly 65 to 75 percent of the organic solvents are emitted in spray booths. An additional 15 to 20 percent of the emissions leave the piece

in the flashoff area. The remaining 10 to 15 percent of these emissions are solvents driven off in the curing oven. (If there is no oven, then emissions are 70 to 80 percent from the booth and 20 to 30 percent from flashoff.) The finished "dried" furniture can still have small quantities of solvent that are slowly released as the furniture is handled or processed. This may represent up to 1 percent of the total solvent originally applied. No furniture manufacturer who participated in this study was controlling emissions through either collection (adsorption) or incineration.

The relative contribution of individual finish coats to overall hydrocarbon emissions was estimated to be:

- Base stains -- 5 percent
- Washcoat -- 15 percent
- Wiping stain -- 5 percent
- Filler -- 10 percent
- Sealer -- 15 percent
- Glaze -- 15 percent
- Topcoat -- 35 percent

Furniture finishes fall into two classes: color coats and clear coats. The color coats include sap stains, body stains, overall stains, filler stains, and glazes. The clear coats are washcoats, sealer coats, and lacquer topcoats. As shown in Table 4, major emission reductions will come from the conversion of clear coats rather than color coats if each finish coating component is replaced with either a waterborne coating having water/solvent blend of 80 parts water to 20 parts solvent or a 100 percent solids finish.

IMPLEMENTATION OF ALTERNATE FINISHING TECHNOLOGY

Conversion of conventional finishes to newer lower hydrocarbon finishes requires a major commitment from raw material suppliers. In the last 50 years, furniture finishes have been based on solvent technology. While some mills have used catalyzed varnishers, the predominant finish polymer has been nitrocellulose. Basic raw material suppliers must work through the finish suppliers to have new materials evaluated by the furniture manufacturers. This can create difficulties.

A second major difficulty is the size of the industry. Although some 230 million l of finishes are used per year, approximately half of these are stains, glazes, fillers, and other color coats which are either low solids or linseed-oil based. The volume of polymerics, namely, the washes, seals and topcoats, has not been great enough to stimulate much creative research on the part of polymer suppliers.

TABLE 4. THEORETICAL EMISSION REDUCTION POTENTIAL

Finish Coat	Current Approximate Emissions in Mg Per Day[a]	Reduction in Emissions in Mg Per Day By Conversion to Waterborne Finish		Reduction in Emissions in Mg Per Day By Conversion to 100% Solids Finish	
		Color Coat	Clear Coat	Color Coat	Clear Coat
Base Stain	30	20		30	
Washcoat	80		65		80
Wiping Stain	30	20		30	
Filler	50	40		50	
Sealer	80		65		80
Glaze	80	70		80	
Topcoat	190	—	150	—	190
Total	540	150	280	190	350

[a]Based on 540 Mg per day total and approximate percent of overall emissions for each process step as presented in Section 4.

Source: Booz, Allen and Hamilton Inc.

SECTION 4

DEVELOPMENT OF THE TRIAL PROGRAM

In developing the trial program, a wide range of information sources was used to ensure maximum contribution. These sources included literature, raw material suppliers, furniture manufacturers, and industry associations.

INFORMATION GATHERING PHASE

Existing literature sources, as well as current journals including Modern Paint and Coatings, Woodworking and Furniture Digest, and Furniture Design and Manufacturing, were reviewed. Documents available from OAQPS on flatwood finishing and the accumulated data bases for the wood furniture source category report were also screened, as well as other data available from the Federal government.

Several of the prime suppliers in the wood furniture finishing industry, including raw material and total systems suppliers, were interviewed. Among these were:

- Raw materials
  - -- Hercules
  - -- DuPont
  - -- Polyvinyl Chemicals
  - -- Sherwin Williams
- Total systems
  - -- Reliance
  - -- Guardsman
  - -- Lilly

The following members of the Southern Furniture Manufacturers Association (SFMA) Technical Committee were also interviewed:

- Bassett
- Bernhardt
- Broyhill
- Drexel Heritage

- Stanley
- Thomasville

Input from SFMA provided an overall industry posture. The National Association of Furniture Manufacturers was not contacted since they are predominately marketing oriented, nor was the Furniture Manufacturers Association of Grand Rapids contacted since their scope is also limited.

Typical pieces of furniture selected for the trial program were a bedroom dresser, a dining room table, a china closet, and a chair.

SUPPLIER SELECTION

More companies showed interest when they realized that an opportunity existed for industry to provide input for developing regulations. Efforts were made to team furniture manufacturers and finish suppliers so that the skills of each could be optimized.

The six previously mentioned furniture manufacturers were approached first and allowed to choose their supplier. Two additions were made to include a high end furniture manufacturer (Henredon) and one of the top finish suppliers (Lilly Company). Lilly then elicited participation from American Furniture. The final selection and matching of the eight furniture manufacturers and the six finish suppliers is presented in Table 5.

Originally, the prime raw materials suppliers, such as DuPont, Rohm and Haas, Hercules, Polyvinyl Chemicals, and Sherwin Williams were to have been included in the program. However, none of the above suppliers was able to suggest a furniture manufacturer outside those already participating with established finish suppliers.

Consideration was given to providing these prime raw material suppliers with partially finished furniture similar to that being processed and having them complete the finishing process in their laboratories. This, however, was outside the scope of the present program and unrepresentative of actual process line application. In addition, a broad enough representation of raw materials was being included to satisfy the program's needs, since most of the prime suppliers were involved through the finish formulators.

PRECONCEIVED PROBLEMS

Problems associated with new finishes are perceived to revolve around aesthetics and performance of the finish for the consumer, as well as application and use in the mill. There is an overwhelming belief within the industry that furniture is sold predominately on its initial visual impression. Not only would loss in this impression be unacceptable to the consumer, but furniture must retain its aesthetic character and performance over 10 to 20 or more years, withstanding conventional household waxes, polishes, foodstuffs, and alcoholic beverages. Within the furniture industry, furniture must be capable of being handled and processed without visible damage; it must also be shippable without "printing."

TABLE 5. FURNITURE FINISHING TRIALS

	Sample Pieces Coated		Finish Supplier					
Furniture Company	Off-Line	On-Line	Guardsman	Reliance	Mobil	Inmont	Spruance	Lilly
Thomasville	X		X					
Drexel Heritage	X					X		
Bernhardt		X	X	X				
Bassett	X		X		X		X	
Broyhill		X			X			
Henredon		X		X				
Stanley		X		X				
American		X	X			X		X

It is generally felt in the industry that changeover to waterborne furniture finishes should initially proceed with low end furniture, where the least number of finishing steps are performed. This would restrict the initial adoption of such systems to lower priced furniture. It is estimated that total conversion of all low end furniture finishes would result in a 50 percent reduction in emissions from the entire wood furniture industry.

More specific problems with new finishes in the mill include repairing furniture, a frequent occurrence both at the factory and at the showroom. A new set of repair procedures will have to be devised, as well as retraining of repair personnel, since waterborne applied finishes are apparently more difficult to remove than conventional solvent finishes. Little or no work, however, has been done in this area.

Because wood absorbs water, the resultant increased grain raising, as compared to solvent-borne systems, will require additional sanding. Application problems of waterborne finishes, such as sagging and running, may require operator retraining.

Current waterborne finishes cannot be sprayed with airless spraying techniques because of basic polymer latex instability under pressure. Conversion back to air spray could partially offset emission reductions and reduce line speeds. Furthermore, producing a few pieces with waterborne finishes is not equivalent to entire finishing rooms filled with waterborne finished furniture, which raises the probable necessity of humidity control to enhance drying rates.

It is generally agreed that flashoff areas may have to be extended to allow proper flashoff of the water. Similarly, curing ovens may have to be modified to drive the water out of the finish, potentially increasing energy costs.

Corrosion of the bulk storage system will occur with waterborne finishes but can be avoided by replacing lines, pump materials, and spray gun fittings with stainless steel units and by lining the inside of storage vessels. This will require substantial capital expenditures. Freezing of the waterborne finishes is also a major concern, since most furniture manufacturers store their conventional solvent-borne finishes outdoors because of fire hazards. Inside storage of waterborne finishes may be required. (Fire hazards are reduced with waterborne finishes.)

Also, the availability of resin systems usable for both existing and future colors is a major concern of both finish suppliers and furniture manufacturers. Waterborne resin systems, once accepted, will have to be produced on a large scale. Suppliers feel that it will take at least a year for compounders to develop full production of the needed resins.

Rapid changes in materials used in manufacturing furniture, such as different woods and plastics, require finishes that are "forgiving" (easily modified). New finishes would have to be as forgiving.

ADVANTAGES

Advantages of waterborne finishes are related to their reduced hydrocarbon content. Fire insurance costs should be lower. Air movement volumes required will also be lower leading to reduced power and heating costs during winter months. Worker exposure to toxic solvents in the mill will be reduced, and potential long range shortages of solvents will be avoided.

The potential for using waterborne and other lower solvent coatings in the wood furniture industry exists, but further testing of such finishes is needed. The adaptation of waterborne topcoats, washcoats, and sealers could effect a reduction of greater than 50 percent of the volatile organics emitted through the finishing of wood furniture. The present program identifies some of the additional testing necessary to clarify the potential for introducing waterborne and other lower solvent finishing systems to the wood furniture industry.

SECTION 5

IMPLEMENTATION OF THE TRIAL PROGRAM

Once the finish suppliers and furniture manufacturers had agreed to participate, the trial program was initiated. Although the program was to have been completed by the end of October 1978, furniture shows that involved firms participating in the program caused delays. Receipt of completed data packages from finish suppliers and furniture manufacturers was also delayed.

TRIAL PROGRAM ORGANIZATION

Eight furniture manufacturers and six finish suppliers agreed to participate in the trial program, which was run with the program management personnel always attending.

Prior to the trials, confirmation letters were sent to each furniture manufacturer, delineating what pieces were to be finished and who the finish supplier would be. A five-page data package was included with this letter to provide information on the finishes and their applications. These data packages were to be completed before, during, or shortly after the trial.

The finishes were applied by representatives of the supplier companies who were assisted by plant finishing personnel. They followed, as closely as possible, typical on-line or off-line finishing schedules. Downstream operations, such as rubbing, stacking, and packaging, also followed actual plant practices. The complete trial program listing furniture manufacturer, finish supplier, furniture finished, and trial date is presented in Table 6. Examples of program approaches follow.

In Bassett's trial situation, the three suppliers involved adopted the following three approaches:

- Spruance -- waterborne sealer and washcoat with other finishes conventional for a target emission reduction of approximately 25 percent
- Mobil Chemical -- waterborne color coats with conventional clear coats for a target emission reduction of 30 to 50 percent
- Guardsman Chemical -- total waterborne system for a target emission reduction of 70 to 80 percent

TABLE 6. PARTICIPANTS IN WOOD FURNITURE FINISHING PROGRAM

Furniture Manufacturer/Contact	Finish Supplier/Contact	Furniture Finished	Trial Date/Comment
Thomasville Furniture Industries P.O. Box 339 Thomasville, North Carolina 27360 (915) 475-1361 Ralph McNeill	Guardsman Chemicals, Inc. High Point, North Carolina 27261 (919) 883-7126 Andy Reidell	Table and dresser finished with waterborne and conventional solvent-borne finishes off-line	September 25, 1978
Drexel Heritage Furnishings Fleming Drive, P.O. Drawer 1299 Morganton, North Carolina 28655 (701) 433-3000 Bill Parks	Inmont Corporation Morganton, North Carolina 28655 (704) 584-1771 Fred Black	Credenza, dining room table, and chairs finished with waterborne finish off-line; credenza finished with conventional finish off-line	October 30, 1978
Bernhardt Furniture Industries P.O. Box 740 Lenoir, North Carolina 38645 (704) 758-9811 Colon Prestwood	Guardsman Chemicals, Inc. High Point, North Carolina 27261 (919) 883-7126 Andy Reidell	Table, chairs, and china closet finished with waterborne finish on-line; china closet finished with conventional finish on-line	October 31, 1978 at Troutman Plant
	Reliance Universal High Point, North Carolina 27261 (919) 883-7181 Gary Currier	Table, china closet, and chair finished with waterborne finish on-line; china closet finished with conventional finish on-line	November 1, 1978 at Lenoir Plant
Bassett Furniture Industries P.O. Box 626 Bassett, Virginia 24055 (703) 629-7511 Jim Minter	Gilbert Spruance Company Bassett, Virginia 24055 (703) 629-7967 Ben Brody	Chest and chair finished with conventional and hybrid[a] finishes off-line	November 2, 1978
	Guardsman Chemicals, Inc. Bassett, Virginia 24055 (703) 629-7967 John Yeaman	Two different dining room tables finished with conventional and waterborne finishes off-line	November 6, 1978
	Mobil Chemical Bassett, Virginia 24055 (703) 629-5533 Don Weisman	Chest and chair finished with conventional and hybrid[b] finishes off-line	November 7, 1978

[a]Trial goal was to replace only the wash coat and sealer with waterborne substitutes and keep the balance of the finish conventional. (continued)

[b]Trial goal was to replace only the color coats with waterborne substitutes and keep the clear coats conventional.

TABLE 6. (Continued).

Furniture Manufacturer/Contact	Finish Supplier/Contact	Furniture Finished	Trial Date/Comment
Broyhill Furniture Industries P.O. Box 700 Lenoir, North Carolina 28645 (704) 758-3622 Z. O. Riggs	Mobil Chemical High Point, North Carolina 27261 (919) 882-6825 Hugh Cates	Dresser, table, china closet, and chair finished with waterborne finish on-line; china closet finished with conventional finish on-line	November 8, 1978
Henredon Furniture Industries Henredon Road Morganton, North Carolina 28655 (704) 765-9641 Don Warren	Reliance Universal High Point, North Carolina 27261 (919) 883-7181 Gary Currier	Chest, dining room table, china closet, and chair finished with waterborne finish on-line; chest finished with conventional finish on-line	November 15 & 16, 1978
Stanley Furniture Company Stanleytown, Virginia 24168 (703) 629-7561 Jim Thornton	Reliance Universal High Point, North Carolina 27261 (919) 883-7181 Gary Falk	Chest, tabletop, night stand, and chair finished with waterborne finish on-line; chest, night stand, and chair finished with conventional finish on-line	November 27 & 28, 1978
American Furniture Company, Inc. P.O. Box 951 Martinsville, Virginia 24112 (703) 632-2061 Ronald W. England	The Lilly Company High Point, North Carolina 27261 (919) 885-2157 Frank Tothill	Dining room table, chair, and case finished with waterborne finish on-line	October 30, 1978
	Inmont Corporation Morganton, North Carolina 28655 (704) 584-1771 Fred Black	Case finished with waterborne finish on-line	October 30, 1978
	Guardsman Chemicals, Inc. High Point, North Carolina 27261 (919) 883-7126 Andy Reidell	Case finished with waterborne finish on-line.	October 30, 1978

Source: Program correspondence and data sheets from participating furniture manufacturers and finish suppliers.

In American's trial situation, the three suppliers involved were assigned the following furniture pieces:

- Guardsman -- one case
- Inmont -- one case
- Lilly -- full suite

Conventionally finished pieces for comparison were either prepared at the same time, pulled off the line from regular production, or selected from warehouse stock.

The trials were often handled entirely by the supplier. Extraordinary attempts were made, particularly with hand finishing, to insure maximum performance from the finishes. Thus, these trials present the best possible results; actual results on-line with less skilled finish appliers will probably not be as good.

DATA COLLECTION

Individual trial reports and other documentation dealing with the trial were provided as a result of the following trials:

- Thomasville Furniture with Guardsman Chemical
- Drexel Heritage with Inmont
- Bernhardt Furniture with Reliance and Guardsman Chemical
- Bassett with Guardsman Chemical, Mobil, and Spruance
- Broyhill with Mobil
- Henredon with Reliance
- Stanley with Reliance
- American with Lilly, Inmont, and Guardsman Chemical

Primary sources of trial information included notes taken by program management personnel at the trials, data acquisition forms filled out by the supplier, and formal requests for additional post-trial impressions from both the supplier and the furniture manufacturer. During the trials, specific information was solicited on costs and potential changeovers required in adopting the new finishes. In selected instances, finish consumption was measured to calculate coverage estimates (in m^2/l). In all cases, notes taken by program management personnel were made available to the finish suppliers and furniture manufacturers.

DATA ANALYSIS

Although the trials were completed in November, many finish suppliers and furniture manufacturers did not complete the data acquisition forms nor respond to the letters sent to them until mid-January. When information became available, both process and finish performance were examined.

Process data were analyzed with particular emphasis on:

- Operational timing, air flows, temperatures, heat requirements, and other application characteristics
- Major process or capital changes required for the new finishes, such as additional manpower or hardware
- Emission reduction potentials for the newer systems
- Costs of the waterborne finishes

Finish performance was assessed for:

- Visual qualities such as appearance, smoothness, color match, and grain raising
- Measured qualities such as resistance to chemical attack, adhesion, and gloss
- Handling qualities such as print resistance, adhesion, and cold crack

After the furniture was finished, it was debated whether to distribute it to interested parties for in-home testing, show it at a furniture convention, or perform additional tests on the finishes and risk future use of the furniture. Pending a final decision, the furniture was moved to a Mayflower warehouse in High Point, North Carolina. On April 24, 1979, the majority of the furniture was displayed in the SFMA theater in High Point, North Carolina during the industry's annual spring marketing show. One manufacturer displayed its furniture in a private showroom; another did not show its furniture because of a delivery mix-up. The furniture of all manufacturers except Bassett has since been sent to EPA in Cincinnati. There it will be placed in EPA facilities so that it can be easily accessed for future evaluation.

SECTION 6

PROCESSING OF THE NEWER FINISHES

When possible, specific time intervals for application and drying of the finish were obtained. When the trials were off-line, allotted times paralleled those for on-line applications, but it was impossible to duplicate line drying conditions. On-line, waterborne finished pieces were often removed from the plant conveyor to complete a specific finish step, such as wiping stain or glaze removal, or to be given a second pass through the oven.

Available information on temperature, humidity, air flows, and other process-related factors was noted in the individual furniture trial reports.

PROCESS FLOW

Process flows are similar for all furniture manufacturers; differences exist in the numbers of steps, timing, and other characteristics. In general, furniture factories are conveyorized to operate at 2 to 14 m/min, allowing pieces to be on-line from 2-1/2 to 12 hours. Heating or drying capacities vary from low-temperature, warm rooms to high-efficiency, high-temperature ovens.

Furniture factories generally operate 8 to 10 hours per day and 5 or 6 days per week. Three breaks occur daily; during these the conveyor line stops. There is a morning break of 10 to 15 minutes, a lunch break of 30 minutes, and an afternoon break of 10 to 15 minutes. Pieces partially finished at the end of the day are left until the following day or after the weekend.

There were two basic differences between normal practice and the finishing trials conducted in this program. In general, the suppliers applied the finishes (on-line or off-line), did the working of the finishes, sanded the pieces, and made all judgments relating to finish appearance and whether or not the finish was dry enough for further processing. The suppliers also provided their own pressure pots and spray guns (air spray) even though some finish components would ordinarily have been applied with airless spray.

OFF-LINE TRIALS

Bassett, Thomasville, and Drexel Heritage conducted off-line trials. Neither Bassett nor Thomasville used any drying between finish application steps, however, a warm room was used at Drexel Heritage.

Total application times for the trials at Bassett varied from 179 to 380 minutes, as presented in Table 7. The Spruance trial, which replaced wash coat and sealer only, took 252 minutes. The Mobil trial which replaced color coats but used conventional clear coats took 179 minutes. The Guardsman trial involving a total waterborne replacement system took 306 to 380 minutes (200 to 225 net, removing non-pertinent time gaps due to sequencing of trial pieces). These times can be compared with a typical on-line time of 176 minutes for similar furniture styles.

Total application time at Thomasville was 290 minutes, not including overnight air drying of the topcoat. This was approximately 50 percent greater than on-line times in regular production. However, this was the first trial in the program, and all participants were somewhat unfamiliar with how to process the finishes and what specific information would be important for the program.

Total application time at Drexel Heritage cannot be accurately estimated since the finish ingredients were not all applied on the same day. In addition, on-the-spot reformulation was done as finishes were applied to either increase or decrease working life.

Although off-line finishing did allow supplier representatives maximum time to apply and process their finishes, such trials produced somewhat unrepresentative products. There was, for example, no drying or at best inadequate drying between steps. The finish was often excessively worked to maximize its performance. Damage resulted from floating debris in the air, and mixing of solvent-borne and waterborne finishes due to improper cleaning of spray guns and pressure pots led to some bare spots and other defects.

ON-LINE TRIALS

On-line trials at Henredon, Bernhardt, Broyhill, Stanley, and American occurred on the normal process conveyor, however the waterborne finished pieces were frequently pulled off to provide extra working, sanding, or drying times. Where possible, oven temperatures were increased to the maximum possible. Finishing application times varied from a low of approximately 3-1/2 hours to over 8 hours. In all cases, these times were longer than those for conventional finishes. The on-line trials are presented in Table 8.

All trials were conducted under low ambient humidity conditions, except for the Bernhardt-Troutman plant which is air-conditioned (21°C, 50 to 55 percent RH). Increasing oven temperatures maximized drying rates for curing the finishes. Line speeds were also reduced to maximize exposure to oven drying. Stanley estimated that a reduction in line speed from 5.5 to 3.7 m/min would result in a 14 percent increase in product cost and a 33 percent reduction in factory capacities.

Finishing room spray booths varied widely, from open-ended to enclosed water wash. These booths exhausted from 280 to 1,000 m^3/min, and all were quoted to meet OSHA standards of 30.5 m/min air velocity across the face.

TABLE 7. OFF-LINE FINISHING TRIALS AT BASSETT

Spruance[a]	Mobil[b]	Guardsman[c]	Conventional On-Line Sequence[d]
Nor stain	Sap stain	Sap stain	Stain
Color coat	Overall stain	Body stain	Enamel
Wash coat	Scuff sand	Wash coat	Toner
Wiping stain	Toner	Wiping stain	Sealer size
Sealer	Wash coat	Sealer	Wash coat
Speck	Sand	Fog glaze	Sand
Cowtail	Wiping stain	Top coat	Filler
Glaze	Sealer	Spatter	Oven at 49°C -- 2-1/2 min
Shade stain	Sand	Cowtail	Cowtail
Build coat	Spatter	Shade stain	Speck
Top coat	Fog glaze	Top coat	Glaze
	Highlight		Shade stain
	Top coat		Build coat
	Shade stain		Top coat lacquer
	Top coat		Oven at 44°C -- 19 min
			Oven at 74°C -- 8-1/2 min
		Total Finish Time	
252 min	179 min	306 to 380 min	176 min Normal line speed (14 m/min)

[a]Conventional finishes except for waterborne wash coat and sealer
[b]Conventional clear coats with waterborne color coats
[c]Total waterborne system
[d]Total solvent-borne finish

Source: Participating furniture manufacturers and finish suppliers

TABLE 8. ON-LINE FURNITURE FINISHING TRIALS

Henredon[a] Reliance	Bernhardt Guardsman	Bernhardt Reliance[b]	Broyhill Mobil	Stanley[c] Reliance	American Furniture[d] Lilly[e]
Sap stain Overall stain Oven at 55°C, 11 min Wash coat Oven at 55°C, 13 min Sand Wiping stain Break, 10 min Oven at 60°C, 15 min Sand Sealer Oven at 60 to 66°C, 14 min Spray pad Top coat Oven at 66°C, 12 min Lunch break, 30 min Highlight/hand pad Oven at 66°C,11 min Spatter/shade stain Break, 10 min Top coat Oven at 66°C, 10 min Top coat Oven at 66°C, 12 min	Equalizer stain Overall stain Oven at 36°C, 10 min Sealer Oven at 30°C, 11 min Glaze Edge filler Oven at 49°C, 52 min Sealer Oven at 33°C, 10 min Sand Shade stain Edge glaze Oven at 60°C, 30 min Cowtail Shade stain Top coat Hand pad Spatter Top coat Shade stain Top coat Oven at 55°C average, 44 min	First Day Sap stain Oven at 19°C, 21 min Wash coat Oven at 25°C, 34 min Glaze Oven at 55°C, 132 min[f] Sealer Oven at 33°C, 25 min Spray pad Oven at 49°C, 67 min Top coat Second Day Hand pad Spatter Top coat Oven at 44°C, 40 min	Wiping stain Oven at 108°C, 1 min Sealer Oven at 108°C, 1 min Sand Glaze Oven at 80°C, 1-1/2 min Flyspeck and shade Lacquer Oven at 77°C, 1-1/2 min Sand and shade stain Lacquer Oven at 86°C, 1-1/2 min Lacquer Oven at 95°C, 3 min Touchup Air dry	Equalizer stain Sap stain Oven at 94°C, 1 min Overall stain Oven at 116°C, 2 min Sealer Oven at 113°C, 2 min Fill glaze 3 zone oven 83°C 83°C } 6 min 105°C Spatter Sealer Oven at 83°C, 3 min Sand Spray/hand pad Oven at 80°C, 4 min First lacquer Oven at 113°C, 4 min Smudge pad Second lacquer 2 zone oven 99°C 113°C } 9 min Third lacquer 2 zone oven 49°C 66°C } 4 min Sand	Mineral streak Sap stain Prestain Overall stain Wash coat Sand Edge filler/edge enamel Wiping stain Oven at 60°C, 30 min Sealer Sand Glaze Top coat Oven at 24°C, 30 min Smudge pad Spatter Cowtail Top coat Top coat
Rub the next day Overall time to finish 8 hours 11 min Normal line speed 3.7 to 5.5 m/min Normal finishing time 5 to 6 hours	Rub the next day Overall time to finish 5 hours 58 min Normal line spped 6.1 m/min Normal finishing time 4 to 5 hours	Overall time to finish (excluding overnight shutdown) 8 hours 15 min Normal line speed 2.4 to 2.7 m/min Normal finishing time 9 to 11 hours	Rub right off line Overall time to finish 3 hours 23 min Normal line speed 9.1 m/min Normal finishing time 2 to 3 hours	Rub right off line Overall time to finish 5 hours 29 min Normal line speed 5.5 to 7.3 m/min Normal finishing time 4 to 5 hours	Rub off line Overall time to finish estimated at 4 to 5 hours[e] Normal line speed 4.9 to 5.5 m/min Normal finishing time 4 to 5 hours

[a]Plant has humidity control in winter but not summer. Trial at 21° to 24°C in plant with nominal 30 percent RH.
[b]Trial at 19° to 24°C in plant with nominal 30 percent RH.
[c]Trial at 21°C in plant with nominal 29 to 35 percent RH.
[d]Trial at 21°C in plant with nominal 30 percent RH.
[e]Three suppliers working on line at the same time. Not possible to track and time all the pieces.
[f]Thirty minutes of this time was lunch break.

Source: Participating furniture manufacturers and finish suppliers.

Total air volume moved by the finishing rooms varied depending primarily on the types and efficiencies of the spray booths. Where available, air volumes were quoted as follows:

- Thomasville -- 14,200 m^3/min
- Stanley -- 7,900; 9,300; 25,500 m^3/min (three different plants)
- Henredon -- 16,300 m^3/min
- Bernhardt-Troutman -- 9,100 m^3/min

Estimates of hydrocarbon content of spray booth exhaust have not been made accurately, although Broyhill has calculated a fuel cost of $1,100 per day to incinerate their emissions.

PROCESS CHANGES FOR WATERBORNE SYSTEMS

Major process and operational changes will be required to handle the waterborne finishing systems.

Humidity Control

Quantities of water vapor being generated would probably require humidity control in the finishing room. In one finishing room, it was estimated that 94.6 l/hr of water vapor would be evolved. Although some would be discharged through stacks, the balance would require removal by other means to insure adequate drying of the finish, avoid mildew or other fungal growth, and compensate for wide swings in ambient humidity, as well as for worker safety and comfort.

Furthermore, the quality of the finish could be affected by the high humidity in the finishing room. Excessive moisture could cause blushing or milkiness of the top coat, and rubbing would be modified because of higher humidity and the softness of the finish. Print resistance also may be a problem, resulting in either longer packaging lines or modification of packaging procedures.

No information was available on the costs of a humidity-controlled facility. Very few such facilities exist; the Bernhardt-Troutman plant is one.

Conversion of Piping and Spray Systems

Repiping of finishing rooms to provide stainless steel pipes, valves, and fittings would be required. Current waterborne finishes are generally corrosive to mild steel pipes, valves, fittings, and pumps. Estimates to convert to stainless steel range from $100,000 to $500,000 per facility depending on the degree of change. This conversion includes replacing or recoating storage tanks, guns, and pumps, as well as the current distribution system.

It was also found that current waterborne finishes must be applied with air sprays rather than airless spray systems. Many finishing rooms have been repiped with high-pressure plastic tubing and airless spray equipment to minimize overspray and emissions; this is particularly true with clear coats. However, the new waterborne polymer systems could not be applied by airless spray because of the instability of the polymer system to high shear and the higher solids content that make uniform application difficult. Efforts on the part of finish suppliers and base polymer producers may overcome this limitation.

Storage Modification

Bulk and drum storage facilities would have to be replaced or modified. Current bulk storage of furniture finishes is provided by aboveground, outside, exposed carbon-steel tanks and underground carbon-steel tanks. Drum storage is primarily outside in drum farms with provision for smaller quantities inside. The bulk storage facilities are in most cases either quite old or designed to meet insurance requirements for storage of flammable liquids. Waterborne finishes would require modification of bulk and drum storage to minimize the corrosive action of the waterborne finishes and the risk to finish quality due to refreezing and rethawing of the waterborne materials.

Corrosive action can be minimized by replacing or relining the tanks. Stainless steel or the less expensive fiberglass reinforced polyester (FRP) tanks could be used, or tank linings such as epoxy and phenolic could be applied. Protection from freeze/thaw damage would require heated storage tanks or placing storage tankage in an enclosed heated environment. Whether the waterborne finishes being manufactured today would meet insurance standards for nonflammability (and thus be capable of storage in nonsecure areas) should be carefully reviewed before making major changes in storage facilities. Finishes in drum quantities can also be stored inside in fiber, phenolic-lined, or plastic drums.

Drying Capacity Increase

Drying capacity must be increased in the finishing room. In all trial situations, additional drying time (or temperature) was required to remove the water and dry the finish. Stanley estimated a 25 percent increase in fuel would be needed to increase oven temperatures by 4.4° to 10°C. Broyhill claims that they have the best oven system in the industry. They were still unable to dry the waterborne finish adequately. Many suppliers feel that elevated temperatures rather than additional time are required to fuse the clear coats and provide a print resistant finish.

For some lower line speed mills having ovens or hot boxes in place, increasing heat input may be adequate, depending on line speed, but for those mills limited in oven number, size, or heat capacity, new ovens would be required. Some mills have very limited drying and heating capacity and would require entirely new oven systems, as well as major modifications of

their conveyor systems. Bassett, for example, is in the process of reworking a finishing room with new conveyor systems and ovens at an estimated cost of $2,000,000.

Storage/Work Area Increase

An increase in plant storage and work areas would be required. Waterborne finishes take longer to develop adequate print resistance compared to solvent-borne finishes. This lengthens the time between application of the final topcoat and placing the finished piece in a crate for shipping. Additional storage space, therefore, would be required to allow the finish to develop adequate resistance through natural aging. Broyhill estimated that an overnight aging would necessitate space for storing 1,500 to 2,500 extra pieces of furniture. Early trial work further suggested that rubbing waterborne finishes that were not completely set resulted in removal of the finish; additional natural aging (and space) would be required at this step. Repair of waterborne finishes also might require additional floor space and facilities, especially during the initial stages of new finish implementation as plant personnel become used to the new systems.

Modification of plant procedures could partially offset some of the needs for additional plant storage space by increasing oven temperatures, reducing line speed for longer exposure to existing oven cure cycles, and adapting rubbing procedures to handle the waterborne finishes. Modification of finish composition may also minimize needs for additional storage space with improved formulations to increase drying rate and set time, rubbing compounds specific to waterborne finishes, and repair compounds for rapid and complete finish removal.

SECTION 7

PERFORMANCE EVALUATION OF THE NEWER FINISHES

The performance of furniture finishes is a critical factor in assessing potential changes in their chemistry or process. With conventional finishes, the supplier coats test panels and adjusts shading, depth, and gloss, as well as modifies formulations for desired chemical or environmental resistances. Because the supplier is responsible for satisfactory finishes, technical specialists are on call to make on-the-spot formulation changes.

During the trial program, finish suppliers provided data on the expected performance of their finishes. Limited testing was also done on completed pieces. However, full-scale tests were not run since damage to the furniture could affect their esthetics and bias comparative evaluation, for example, at a trade show.

VISUAL QUALITIES

Total waterborne finishing systems do not produce a commercially satisfactory looking piece of furniture in the judgement of all of the furniture manufacturers who participated in the trials and of those manufacturers and retail firms who viewed the furniture during the subsequent industry market show in High Point, North Carolina in April 1979. Furniture appearance is the most critical factor in assessing newer systems. Although great strides have been made in the development of waterborne finishes in the past years and during the trial program, all furniture manufacturers and finish suppliers felt that none of the pieces produced would be commercially acceptable when compared with conventional finishes. However, they were optimistic about the future.

Several casual observers at the furniture show commented that some of the waterborne finished furniture had an "antique" look that they favored over similar conventionally finished pieces. Although these people were not experienced finish evaluators, their opinion does indicate that waterborne finished furniture might appeal to certain buyers.

Grain Raising

Water in contact with wood disturbs the surface by causing grain raising (popping). This occurred in all on-line and off-line trial situations. Drexel Heritage reported a minimal grain raising on their very light-colored styles, while Spruance observed serious grain raising on dark-colored oak, even when they applied waterborne wash coats or sealers

over conventional base stains. After rubbing, bare wood showed through the distress marks of chain-distressed bleached hardwood at Henredon.

Grain raising, due to its swelling characteristic, prevents subsequent finish components from providing the desired depth of shade or coloration. Color depth and shade were not equivalent to conventional finishes at American, whereas color depth and shade could not be achieved at all at Broyhill. At Bassett, finished pieces looked darker and duller.

In addition, grain raising produces a very rough surface that gives an undesirable tactile sensation even after sanding. In fact, normal sanding procedures were inadequate to remove high spots developed by the raised grain. Extra sanding on flat surfaces did minimize the surface roughness, but drawer edges, table legs, and other exposed grain areas remained rough even after additional effort.

Applying a sealer to the wood to minimize grain raising was suggested but not evaluated. This idea was viewed with skepticism since a sealed wood could not be easily stained, colored, and highlighted.

Gloss and Depth of Character

The waterborne topcoats did not meet currently accepted gloss standards. For example, one furniture manufacturer who seeks a 60 gloss obtained only 35 to 40.

Without exception, the waterborne finishes were hazy and visually unacceptable in comparison to conventional finishes. It was difficult to see through to the wood, and furniture manufacturers complained of poor clarity, lack of luster or color depth, and milky appearance. The furniture had a sandy, flat look that was cloudy and cold with a greyish cast. The lack of a warm and deep finish resulted in unattractive furniture.

One furniture manufacturer felt that while the lower end manufacturer may not suffer appreciable appearance loss, high end manufacturers will. All manufacturers were concerned about the commercial disadvantage of merchandising waterborne finished pieces versus conventional pieces.

Graininess of Finish

In addition to grain raising, graininess was caused by the adherence of more dust, lint, and fuzz to the pieces since they dried much more slowly than conventional finishes. Coagulated waterborne finish particles that were not filtered out or that accumulated during spraying also contributed to graininess.

Improvements in gloss, sheen, and surface depths would require reformulation and polymer development to improve performance during spraying.

Surface Sheen

"Orange peel" occurs when individual polymer particles do not knit together to form a continuous adherent film. This can result in bumpy and nonuniform smoothness, or actual breaks in the film integrity evidenced by craze marks. Control of orange peel with waterborne finishes requires humidity- controlled finishing rooms.

Other Factors

Slip or slickness of the surface was not as pleasing as that of conventional finishes. The incompatibility of waterborne finishes with prefinished parts or thin veneers gave rise to more cracks, crazing, and actual removal of the prefinish. Failure to wet flatwood prefinished components with the waterborne finishes at Broyhill resulted in a puddled look after drying. The printed finish on prefinished table tops at Bernhardt was dissolved by the waterborne stains that produced a crazed, cracked, and mottled appearance. Waterborne stains also created microcracks in veneers at Thomasville. Modification of prefinished stock to provide pieces more amenable to finishing with waterborne systems may be possible with further efforts.

MEASURABLE RESULTS

Mills vary in their ability to test the measured quality of the finish, from total reliance on the supplier to a complete evaluation of their own. These performance tests can only roughly indicate how durable the finish will be in actual service, since no one knows how the finish will stand up to normal wear and tear over 10 to 30 years.

Chemical Resistance

Resistance to household chemicals is important to long-term aesthetics, a function primarily of the top coat rather than the color coats. Chemical resistance tests include ASTM D-2571-76 for resistance of factory-applied coatings to oils, greases, cosmetics, and other household chemicals; ASTM D-3023-72 for resistance to stains and reagents; ASTM D-1308-57 for the effect of household chemicals on clear and pigmented organic finishes; and garbage tests, such as the one used by Drexel Heritage and shown as follows:

Materials applied to surface for 24 hours except alcohol (2 hours), cologne (2 hours), and nail polish remover (until solvent evaporates):

Alchohol	Lysol®	Lemon juice
Cologne	Clorox®	Vinegar
Naphtha	Mustard	Coffee
Nail polish remover	Catsup	Water
Bluing	Vegetable oil	Grape juice
Iodine	Margarine	

Where highly critical resistance is required, conventional finishes may be inadequate, and catalyzed varnishes will be required.

Chemical resistance of waterborne finishes is generally acceptable except for resistance to alcohol and cleaning or waxing compounds containing naphtha-type solvents. Suppliers report that such finishes absorb alcohol-, water-, naphtha-, and oil-based staining compounds, but demonstrate acceptable general garbage resistance that improves with age. The mills observed poor resistance to alcohol, bluing, Lysol®, and Clorox®.

UV Resistance

Change in color or shade upon exposure to artificial sunlight is an undesirable factor for both color coats and clear coats. While standard tests were mentioned for this property, suppliers expect adequate to somewhat improved UV resistance in the waterborne finishes, particularly with the acrylic-based finishes.

Adhesion

Adhesion of the finish to the wood and cohesion between various finish components is necessary to accommodate changes in styles, woods, and the use of plastics. Adhesion tests include ASTM D-2197-68; the Gardner balanced scrape adhesion tester; the U.S. government organic coatings adhesion tester; the Bell adhesion tester; and crosshatch, tape pull, or nickel scratch tests.

Based on the data developed during the trial program, adhesion of the waterborne finishes is acceptable. One supplier expected poor adhesion prior to the trial, but on-line adhesion testing was satisfactory.

Other Factors

Humidity resistance testing through ASTM D-2247 and 3459 that expose finishes to varying levels of humidity and water condensation showed poor performance from the waterborne finishes. Scrub and mild abrasion resistance testing through ASTM D-2486 that expose finishes to various materials that might rub across the surface, such as wet cleaning rags, books, and plastics, indicated marginal performance of the waterborne finishes prior to thorough drying and aging.

PRINT RESISTANCE

Furniture is packaged, crated, and shipped countrywide from the furniture factory. When furniture is uncrated, packing materials must be able to be removed cleanly and leave no mark or "print" on the finished surface. This is termed print resistance.

Several test procedures measure print resistance from ambient temperature and humidity to elevated temperature (hot print) and elevated humidity. These include ASTM D-2091-67; in-plant stacking of finished table tops with canvas cloth separators; in-plant packaging of pieces for storage in a warehouse; and oven aging in a finish supplier laboratory after which finished panels are stacked.

Rapid development of print resistance is important in space-limited furniture factories. Conventional finishes develop print resistance so rapidly, pieces can be crated and shipped almost immediately after production. Newer finishes would need similar attributes to avoid large holding areas for natural aging.

Furniture finishes must withstand a static load of up to 28 kPa without printing to meet the industry's minimum standards. Most mills aim for 28 kPa, although Broyhill stacks furniture six high and needs at least a 70 kPa print resistance.

In general, waterborne finishes have unacceptable print resistance, although resistance is said to improve with natural aging. Hot print resistance and print resistance under humid conditions is also poorer than with conventional finishes. One supplier estimated that print resistance would be unacceptable 3 to 4 hours after finish application, become submarginal after overnight aging (7 to 14 kPa), and be marginally acceptable (14 to 21 kPa) in 3 to 4 days. Stanley stacked waterborne finished table tops with spacers right off the finishing line; when pieces were selected for rubbing the next day, print marks were apparent. Most of the waterborne finished pieces were not cartoned directly off the line, but were aged 24 to 48 hours. Therefore, the circumstances were not representative of the typical furniture plant.

Print resistance is expected to be acceptable on some lines, but unacceptable on high-speed conveyorized lines or lines with minimum heat capacity, and definitely unacceptable under hot print conditions. Supplier projections of fair initial print resistance proved unacceptable, leading mills to expect printing if furniture is packaged right off the line.

Two mills, however, reported satisfactory print resistance. Drexel Heritage reported no printing with their print test on the off-line trial run of a total waterborne finish system. They also reported no printing on a piece that had waterborne coats up to the three topcoats of conventional lacquer. Bernhardt reported satisfactory print resistance by phone, but did not confirm this in writing.

RUBBING CHARACTERISTICS

Mills differ in their rubbing procedures. Some mills do not rub at all or rub only certain styles. Others rub their pieces on-line after finishing or store pieces overnight for rubbing the next day. In general, high end pieces receive more rubbing than middle quality pieces; while low end pieces receive almost no rubbing at all. Approximately one-fourth to one-third of furniture undergoes some type of rubbing.

Current rubbing practice involves waxes, rubbing compounds, steel wool, and buffing. A typical hand-rubbing with machine assistance uses:

- Grade 1 emery paper and rubbing oil
- Grade 2 emery paper and rubbing oil

- Grade 1 rubbing cloth and rubbing compound
- Grade 2 rubbing cloth and rubbing compound
- Steel wool
- Wool buffing wheels

Rubbing can occur immediately on-line after finishing or at some later point. Most pieces at Stanley are rubbed on-line after application of the finishes, although table tops are stacked and rubbed the next day. Rubbing at Henredon and Bernhardt generally takes place the next day. Rubbing at Broyhill is on-line after application of finish, while Bassett does not rub its major styles.

Rubbing of the waterborne finishes led to significantly different results than that with conventional finishes. Broyhill reported that flat surfaces would not rub out properly for the desired appearance even when passed through the rubbing station three times. Stanley passed pieces through rubbing two times without success, while Henredon actually rubbed through the finish to bare wood in spots attempting to achieve the sheen and gloss standards. Bassett, on the other hand, indicated that they may have to rub some styles that are not now rubbed. Finally, Drexel Heritage reported that their conventional rubbing procedures were not able to bring up the surface character to an acceptable level and further estimated that 50 percent more time and effort may be required to rub the waterborne finishes.

Modifications in procedures or rubbing materials will be needed to develop the necessary surface appearance from current waterborne finishes. This presupposes that the waterborne finish materials are chemically capable of producing the desired gloss, luster, and smoothness.

REPAIR

Repair of furniture on-line, in the inspection room, and at the dealer or showroom is an accepted fact of life. Up to 25 percent of all furniture receives some type of repair prior to purchase by the consumer. Repair procedures must correct the defect without being noticeable within that piece as well as among other unrepaired pieces.

Stripping

Total stripping of waterborne finished pieces presents a serious problem. When pieces inadvertently processed with some waterborne and some conventional finishes were totally stripped for repair, the conventional finishes were removed easily, while the waterborne finishes were not removed readily even when using hard bristle brushes. Test panels with waterborne finishes were also difficult to clean off. In fact, although some suppliers indicate that major repair should be possible, it has yet to be demonstrated.

Development of new furniture stripping chemistry for waterborne finishes will be required to remove the defective or old finish completely and economically. However, many of these pieces are made of different materials such as plastics, metals, and certain woods that could be adversely affected by the strippers. Veneers, print-coated hard board, and bonding adhesives may also be adversely affected. Disposal, recovery, or reuse of the strippers must be considered, and a technology that commercial refinishers could use to remove waterborne finishes for their customers must also be developed.

Color Repair

Intermediate color changes, highlighting, or shade matching is difficult with waterborne finishing materials. In many instances, due to line stoppages, uniqueness of a piece of furniture, or the need to match a color or shade, individual pieces may have to be processed by themselves and then returned to the line.

Conventional finish components wet one another, flowing together to achieve the desired effect, and if not correct can be reworked quickly to the proper level of color or shade. When dry, on the other hand, waterborne wash coats and sealers do not rewet and allow penetration of stains and color coats for shading or color match. Furthermore, the colors, if adherent at all, can be readily removed in final rubbing, leaving light and dark areas.

Spot Repair

Small spot repair of waterborne finishes can be accomplished by current burn-in techniques. Small areas can be refluxed and reflowed by conventional, pointed hot-iron procedures. The appearance of these touch-up areas seems acceptable based on the limited experience to date.

Showroom Repair

Showroom or merchandiser repair is an unknown quantity outside the scope of this program. Typical repairing techniques used by merchandisers of furniture would have to be established and applied to typical waterborne finished pieces. If these techniques prove unsatisfactory, new techniques or chemical systems would have to be developed.

SECTION 8

EMISSION REDUCTION POTENTIAL FOR THE NEWER FINISHES

Each supplier company provided information on the individual finishes used during the trials. The suppliers completed the forms as requested, with excellent attention to detail. Certain reports, however, did require several followups. The following analysis was then based on the available information.

COVERAGE VALUES

Stated coverage values will have a significant impact on emission reduction potential. For example, emissions from a finish estimated at 9.8 m^2/l will be approximately half that of a finish estimated at 4.9 m^2/l, assuming the same solids content and dry film thicknesses. Coverage differences are due to differences in how the finish is applied and the skill of the operator.

Suppliers differ considerably on estimated coverage per liter for known finishes (conventional solvent-borne). Their estimates are given in Table 9. Since experience with waterborne finishes is limited, estimates tend to be broader; however, higher coverage rates are suggested, as shown in Table 10. Actual measured values from three trials bracket the estimated coverage in some cases, but are much higher in others, as presented in Table 11. Finally, a summary of the estimated and actual coverage values for key finish components is provided in Table 12.

Based on the accumulated data and subject to further confirmation, the following coverage values have been used in developing overall estimates of emission reduction potentials for the industry (individual plant-by-plant coverages vary by as much as 50 percent):

	Average Estimated m^2/l	
	Solvent-borne	Waterborne
Stains	9.83	9.83
Wash coat	6.14	7.37
Wiping/stains/glazes	9.83	7.37
Sealers	6.14	7.37
Pads, spatters, cowtails	36.86	49.15
Top coats	5.53	6.14

TABLE 9. COVERAGE VALUES FOR CONVENTIONAL SOLVENT-BASED WOOD FURNITURE FINISHES

	m^2/l							
	a	b	c	b	d	b	e	c
Prestain	6.02	6.76						
Sap stain		6.76	2.4			6.76	6.14	2.4
Overall stain	6.02	6.14	2.4			6.76	6.14	2.4
Equalizer stain		6.76		6.76				
Wash coat	5.53		2.0	6.14		6.14	3.93	2.0
Toner								
Wiping stain	9.83		13.8		9.83		6.14	13.8
Glaze	9.83	6.14	13.8	6.14	9.83	6.14	6.14	13.8
Sealer	5.28	6.14	5.46		5.48-6.14	6.14	3.93	5.46
Top coat	4.55		5.55	6.14				5.55
Paid stain			Very High		73.73	9.83		
Spatter		9.83	Very High			9.83		
Cowtail		9.83	Very High	9.83	73.73			
Brushmark		9.83			73.73			2.4
Shade						9.83	14.7	
Smudge pad		9.83				9.83		
Top coat	4.55	6.14	5.55	6.14	5.48	6.14	4.92	5.55

[a]The Lilly Company

[b]Reliance Universal

[c]Guardsman

[d]Inmont

[e]Spruance

Source: Participating finish suppliers

TABLE 10. COVERAGE VALUES FOR WATERBORNE WOOD FURNITURE FINISHES

	m^2/l										
	a	b	c	b	c	d	b	d	c	e	b
Prestain	12.2										
Sap stain	12.2	6.76	6.76	6.76			6.76		6.76		6.76
Overall stain	12.2	6.76	6.76	6.76	6.76	6.14	5.28	19.7	6.76		6.76
Equalizer stain				6.76							
Wash coat	7.99		6.14		6.14	3.34	4.03	11.1	6.14	3.98	12.6
Toner											
Wiping stain	8.65	5.28		5.28		6.14	5.28	19.7	6.14		5.28
Glaze	8.65	5.28	6.14	5.28	6.14	6.14	5.28	19.7	6.14		5.28
Sealer	6.76	12.6	6.14	12.6	6.14	7.13	12.6	11.1	6.14	3.93	12.6
Top coat	5.53	10.7		10.7	6.14	8.43			6.14		10.7
Pad stain			9.83	Unknown	9.83	6.14	5.28	73.73			
Spatter			9.83	Unknown	9.83	6.14	5.28				
Cowtail			9.83	Unknown		6.14	5.28	73.73			
Brushmark			9.83					73.73			
Shade						6.14	5.28				6.76
Smudge pad			9.83		9.83						
Top coat	5.53	10.7	6.14	10.7	6.14	8.43	10.7	9.83			10.7

[a]The Lilly Company

[b]Guardsman

[c]Reliance Universal

[d]Inmont

[e]Spruance

Source: Participating finish suppliers

TABLE 11. COVERAGE VALUES BASED ON ACTUAL MEASURES

	m^2/l					
	Conventional Finishes			Waterborne Finishes		
	a	b	c	d	b	c
Sap stain		19.0	50.38			43.01
Overall stain		8.60	18.9			21.6
Equalizer stain	73.73			61.44		
Wash coat		4.30	12.5		35.4	12.5
Toner			19.1			37.85
Wiping stain	7.62	9.88	10.6	5.04		13.8
Glaze		11.1	50.38(Fog)			50.38(Fog)
Sealer	8.23	3.69	11.7	8.11	37.4	11.7
Top coat	3.81			5.41		
Spatter				294.90		
Shade		33.23	151.1	156.1		151.1
Top coat	3.81	5.14-5.80	9.46	5.41		9.46

[a]Based on triple dresser, dining room table, chair, and china closet totaling 9.2 m^2 (Mobil).

[b]Based on a chest, chair, and panels of 7.86 m^2 (Spruance).

[c]Based on a dresser and chair of 4.5 m^2 (Mobil).

[d]Based on a china closet of 3.2 m^2 (Mobil).

Source: Participating finish suppliers.

TABLE 12. AVERAGE COVERAGE VALUES

	m^2/l			
	Solvent-borne Estimated	Solvent-borne Actual	Waterborne Estimated	Waterborne Actual
Stains	6.14	8.60-73.73	7.37	21.6-61.44
Wash coat	6.14	4.30-12.5	7.37	3.93-12.5
Wiping stain-glaze	9.83	7.62-10.6	6.14	5.04-13.8
Sealers	5.53	3.69-11.7	7.37	4.15-11.7
Top coats	5.53	3.81-9.46	6.14	5.41-9.46
Pads, spatters, etc.	Very high	33.18-151.1	Very high	151.1-294.90
Top coats	5.53	3.81-9.46	6.14	5.41-9.46

Source: Participating finish suppliers

EMISSION REDUCTION POTENTIAL

Suppliers' coverage estimates for both waterborne and conventional finishes laid the groundwork for estimating emissions per unit area (100 m^2). In some cases, coverage figures were either not presented or were unreasonably low. In these situations, averaged values were used. Table 13 shows the results of the emission data analysis from all the trials.

Emission reductions obtained in the program ranged from 26 to 94 percent. Replacing wash coat and sealer waterborne substitutes resulted in a 26 percent emission reduction, while a 30 percent reduction was obtained by converting color coats to waterborne and retaining conventional clear coats. Totally converted finishes yielded up to 94 percent emission reduction.

Emission reduction potential differed significantly among suppliers during the trials. This suggests different approaches to the reduction of emissions, as well as different assumed average values. The following table exemplifies this wide percentage range:

	Percent Emission Reduction
Guardsman	55; 61
Lilly Company	79
Mobil	83
Reliance Universal	87; 92; 93
Inmont	94

Variations also exist in ultimate emissions per unit area, from 5.9 to 58.7 kg/100 m^2 for reported waterborne finishes.

These differences are the result of individual suppliers establishing higher or lower levels of hydrocarbon in their waterborne finish. Differences in estimated coverage values also contribute to this wide range. Another contributing factor is some suppliers' uncertainty about coverage values for the newer finishes. This led to conservative first approximations.

Significant differences (almost two to one) also exist in the estimated levels of emissions from conventional systems; no distinction is made between high end, medium end, or low end furniture. This is probably due to the use of estimated coverages, which significantly alters emissions per unit area. Typical emission levels are as follows:

	Emissions kg/100 m^2
Stanley-Reliance	160
Henredon-Reliance	120
Bernhardt-Reliance	98.8
Drexel Heritage-Inmont	99.8
Bassett-Spruance	120
Bassett-Guardsman	87.1

TABLE 13. ESTIMATED HYDROCARBON EMISSIONS REDUCTION POTENTIAL

Furniture Manufacturers-Finish Supplier	Estimated kg of Hydrocarbon Emitted per 100 m^2 of Surface Covered[a]		Potential Percent Reduction
	Conventional	Waterborne	
Drexel Heritage-Inmont	99.8	5.9	94
Bassett-Spruance	120	89.0[b]	26
Bassett-Guardsman	87.1	34	61
Bassett-Mobil	43	30[c]	30
Broyhill-Mobil	71.4	12[d]	83
Bernhardt-Reliance	98.8	7.3	92
Bernhardt-Guardsman	-	58.7[e]	-
Stanley-Reliance	160	12	93
American-Lilly	136	29	79
American-Inmont	-	11	-
American-Guardsman	-	24	-
Henredon-Reliance	120	16	87
Thomasville-Guardsman	81.2	36	55

[a]Average values taking into account supplier-estimated overspray values and different furniture pieces.

[b]Trial goal was to replace wash coat and sealer only with waterborne substitutes and keep the balance conventional.

[c]Trial goal was to replace color coats only with waterborne substitutes but keep conventional clear coats.

[d]Calculated values based on actual finish usages.

[e]Values appear high, based on other trial data.

Source: Participating finish suppliers.

Emissions from each finish component as a percentage of total emissions can also vary widely. The majority of emissions from wood furniture finishing comes from the clear coats rather than color coats, as was shown in Table 4. The breakdown is roughly as follows:

- 65 percent of emissions from clear coats
  - -- 15 percent from wash coat
  - -- 15 percent from sealer
  - -- 35 percent from top coat
- 35 percent of emissions from color coats
  - -- 5 percent from base stains
  - -- 30 percent from wiping stains/fillers/glazes

Although there are wide variations in the percent of total emissions from each process component, as shown in Table 14, the averages for overall clear and color coats are close to the original estimates of 65 and 35 percent, respectively. Wash coat, sealer, and top coat emissions are quite close to their estimates, as are total color coat emissions, but base stain and wiping stain/filler/glaze emissions are reversed in their relative importance.

TABLE 14. EMISSIONS FROM INDIVIDUAL FINISH COMPONENTS

	Percent of Total Emissions from Each Process Component									
	Drexel[b]	Stanley[b]	Broyhill[c]	American[d]	Bernhardt[e]	Henredon[b]	Thomasville[b]	Bassett[f]	Range	Average[g]
Base stain[a]	28	49	10	37	29	37	28	26	10-49	31
Wash coat	--	--	--	10	13	10	16	16	10-16	13
Wiping stain/ filler/glaze	8	13	--	9	11	14	9	20	8-20	12
Sealer	26	14	12	10	24	19	16	15	10-26	17
Top coat	39	24	78	34	23	19	31	24	19-78	34
Total	101	100	100	100	100	99	100	101		

[a]Includes cowtail, spatter, fly speck and other highlighting stains.

[b]Based on sole supplier's estimates.

[c]Based on actual measurements.

[d]Based on supplier's estimates (Lilly).

[e]Based on supplier's estimates (Reliance).

[f]Based on supplier's estimates (Spruance).

[g]Does not add up to 100 percent as some components were not used in all trials.

Source: Participating finish suppliers.

SECTION 9

COSTS OF THE NEWER FINISHES

During the trial program, as much information as possible was developed on the cost of conventional and newer finishes. Finish suppliers were reluctant to give this information as any cost data could be used by their competitors, and they did not want to commit themselves to anything that might fix their pricing strategy in the future. For these reasons, caution is suggested in the use of any cost data in this chapter.

All suppliers selected waterborne materials for their new finish systems, after assessing the available polymers and additives for their potential to produce finishes at reduced solvent cost. No high solids, per se, or other lower hydrocarbon finishes were evaluated in this program.

OVERALL COST

Overall cost data indicate higher unit costs for most, but not all, waterborne finishes. See Table 15.

Waterborne top coats were quoted as 50 to 300 percent more costly than their solvent-borne counterparts. Waterborne sealer coats cost 50 to 100 percent more, and waterborne washcoats are 25 to 50 percent more expensive. Waterborne heavy color coats (such as wiping stains and glazes) costs are 50 to 100 percent higher, while waterborne prime color coats (such as prestains, sap stains, and overall stains) are equivalent or somewhat more costly. Finally, waterborne accenting color coats (such as spatter, pad, and cowtail stains) are equivalent to conventional finish costs.

APPLIED COSTS

Since coverage for waterborne finishes appears somewhat higher than for solvent-borne finishes, the applied costs of the two finishing systems may be closer. More data are needed to confirm this. The wide variation in estimated coverages for solvent-borne finishes and the limited experience with processing waterborne finishes and optimizing application techniques are contributing factors to a reassessment of these applied costs. However, deficiencies in the performance of waterborne systems may have to be corrected by increased usage, thereby reducing coverage per gallon.

Furniture manufacturers' estimates of costs per liter were generally based on the development pricing of their suppliers. Therefore, lower

long-term costs could be expected as waterborne finishes go into general production. As sales volume increases, additional research may result in either less expensive polymers or polymers having improved properties.

Not all finish suppliers provided cost data. One supplier would quote only an "increase over conventional finishes," and another supplier who is polymerizing proprietary materials did not want his cost estimates included.

TABLE 15. COST OF FINISHES

Finishing Material	$/l	
	Solvent-borne	Waterborne
Prestain	0.926-1.19	0.926-1.19
Sap stain	0.794-1.06	0.794-1.06
Overall NGR stain	0.595-1.32	0.926-1.32
Wash coat	0.728-0.992[a]	0.794-1.39[a]
Wiping stain	0.926-1.26	1.59-2.12
Sealer	0.767-1.19[a]	1.32-2.25[a]
Glaze	1.06-1.59	1.59-2.12
Top coat	0.860-1.19	1.59-3.04
Spatter stain	1.72-1.98	1.72-1.98
Pad stain	1.72-1.98	1.72-1.98
Cowtail stain	1.32-1.59	1.32-1.59

[a]One supplier states that waterborne wash coat and sealer will cost 25 to 28 percent more than those that are solvent-borne.

Source: Participating finish suppliers.

SECTION 10

OTHER ISSUES BEARING ON THE IMPLEMENTATION OF WATERBORNE FINISHES

During the program, major issues were raised by suppliers, users, and members of the study team.

MANPOWER

In all trial situations, more personnel than normal worked during finish applications. The suppliers' and furniture manufacturers' unfamiliarity with the new finishes and the suppliers' anxiety that the finishes be applied and handled properly so that the pieces look well for demonstration purposes contributed to this excess manpower. The variable working life of waterborne finishes, particularly glazes, and the slower drying rates for waterborne finishes in many cases caused trial pieces to be pulled off-line for further workup so as not to slow the whole plant down; they were also often sent through a drying oven for a second pass.

Initial full-scale plant implementation of waterborne finishes will require additional personnel in the following areas, although improvements in technology could minimize this need in the long term:

- Sanding -- three to ten additional people
- Fill glaze and wiping stain -- four to six additional people
- Highlighting and accenting -- two to five additional people

This additional need for personnel represents an approximate 15 to 25 percent increase in the finishing work force.

Extensive retraining of finish application personnel would be required for handling the different performance of waterborne finishes. For example, waterborne clear coats go on milky and turn clear on drying, a sequence visually different from conventional finishes. Working characteristics of fillers and glazes are likewise different, while adjusting color and staining on-the-run presents new problems since clear sealers and wash coats are not readily rewet or reworked.

Additional personnel would also be required in rubbing, which applies to all high end, most medium end, but only a small proportion of low end furniture. With a normal complement of 8 to 10 people on a rub line, 2 to 5 additional personnel may be required for waterborne finishes.

While minor spots up to the size of a quarter can be repaired with existing repair techniques, major repairs require stripping of the entire finish. Although finish removal technology will undoubtedly change, current procedures do not remove waterborne finishes easily. Therefore, the major repair staff at each plant would probably have to be increased from one to two people to six to eight people to allow enough time to strip the waterborne finished furniture.

WATER POLLUTION

Increased use of waterborne finishes will increase water pollution from the spray areas. Overspray of conventional systems now results in collection of particulate matter on filters or entrapment in water-washed spray booth hardware. The water is then periodically dumped to municipal or plant sewage systems. Solvent vapors either exhaust to the atmosphere from the spray booth or volatilize from the collected water.

Particulate matter from waterborne systems would collect in similar amounts but differ in type from solvent-borne particulates. It could also be removed by filters and water-washing hardware. Emulsifiers, stabilizers, and other soluble waterborne finishing components, however, would remain in the wash water exiting the spray booth and present a water pollution potential. These ingredients collected in the spray booth wash water could affect primary or secondary sewage sludge treatment at the plant or municipal facility.

Cleanup, washup, and other indirect applications would also increase water pollution. Cleanup and washup of waterborne materials usually use detergents and cleaners that add to the water pollution load. In addition, changeovers between suppliers may necessitate dumping and refilling wash water booth recirculation tanks if polymer systems are incompatible to prevent sludge or coagulated latex from forming and plugging lines, filters, and pumps.

TECHNICAL SUPPORT

Furniture producers rely heavily on their suppliers for in-plant technical services. The supplier, on call 24 hours per day, does all the color matching and prequalifies all finishes by testing in his own laboratories. The supplier represents the only significant source of information on new finishes, which means supplier personnel are expected to make any changes and correct any mistakes.

Furniture producers would be incapable of converting to waterborne finishes without the full-time support of the supplier. Suppliers, however, do not have the staff to customize finish systems and support all their customers' conversion programs. Instead, they would have to selectively choose key customers with which to work, putting other customers at a technical disadvantage.

FINISH INCOMPATIBILITY

Each finish supplier develops a finish that is unique to the customer he serves. In general, solvent-borne finishes are miscible with one another; it is often adequate to flush the lines with one to insure the removal of the other. Solvent cleaning completes the process. In fact, differences between suppliers in the conventional nitrocellulose-based clear coats are so minimal that these coats can often be intermixed in bulk storage facilities and used interchangeably.

Waterborne finishes are based on the characteristics of a given base polymer, and each supplier's base polymers have emulsifiers and stabilizers unique to it. Further formulation of these polymers usually involves a balance between properties and stability that is different for each finish; therefore, combining them in storage could result in massive formulation instability or coagulation. This incompatibility could require a furniture producer to install separate storage facilities or be limited to only one supplier.

RAW MATERIAL AVAILABILITY

Only a certain number of available dyestuffs and pigments can be dispersed in waterborne systems. This could limit new furniture colors and styles. While one major finish supplier is developing his own proprietary finish polymers, time is required for piloting, semiworks scaleup, and full-scale production experimentation and construction. Another major raw material supplier is considering building a multimillion-pound-per-year plant, but again time would be required for engineering and construction. While material constraints are not insurmountable, all are heavily influenced by rapid technological change.

OPERATIONAL MODIFICATION

Many of the considerations affecting users of waterborne finishes will affect producers of the finishes as well. These include:

- Modification of outside carbon steel bulk and drum storage to handle waterborne finishes
- Protection to minimize freeze/thaw damage
- Modification of piping, valves, and pumps to handle waterborne materials

Unique process and facilities problems will also affect formulators of waterborne finishes. For example, conventional off-specification finish batches can be blended into new batches, but coagulated waterborne polymers cannot be reverted and reused; this raises the additional problem of disposal of off-specification materials. Water pollution could result from tank washing and tailings. Since most suppliers have more than one line of product for many industry areas, dual raw material storage facilities for major system changeover would be required. Dual warehousing of finished products would also increase space requirements.

SECTION 11

ADD-ON VOLATILE ORGANIC CARBON EMISSION CONTROLS

INTRODUCTION

Emissions from conventional solvent-borne furniture coatings can be reduced by means of add-on control devices, such as activated carbon adsorption beds, gas/liquid extraction columns, and incinerators. Preliminary screening of such control devices by the authors limited the options to thermal or catalytic incineration, either with or without primary heat recovery. Carbon adsorption, gas/liquid extraction, and other advanced technologies were eliminated, primarily because of their high initial installed capital costs and secondarily because such technologies have fared rather poorly in the past under the same adverse operating conditions of low VOC concentration and high air flowrates in other industries. Ninety percent of VOC emissions from a spray booth or drying oven can be directed to an incinerator where these emissions can then be burned with a combustion efficiency of at least 90 percent, thus yielding an overall control of 81 percent of the original emissions.

The following disadvantages and problems present themselves if incinerators are used to reduce VOC emissions from the wood furniture finishing industry:

- Incinerators are not currently used in any wood furniture finishing room in the United States; this means borrowing the technology from other coating industries

- The nitrocellulose lacquers in conventional finishes would probably require that each spray booth or curing oven have its own incinerator to prevent nitrocellulose buildup in the ductwork of a manifolded system since such buildup creates a fire hazard; this buildup problem may not allow the use of one large incinerator with a manifolded system. Therefore, the industry would not have the economy of scale many other industries have.

- Future availability of fuel required by incinerators is questionable

- High air flowrates (4,000 to 24,000 Nm^3/min) and low concentrations of organic vapors from furniture finishing rooms make incineration a relatively inefficient and cost- ineffective option

- Nitrogen oxides (NO_x) generation could be excessive with many individual incineration systems; little benefit may be gained by trading VOC emissions for NO_x emissions

INCINERATOR COST ESTIMATES BASES

Incinerators for wood furniture finishing room spray booths and curing ovens are expensive. In order to compute their cost, typical exhaust parameter values were developed for small, medium, and large spray booths and curing ovens. These values are given in Table 16.

Next, bases had to be established for estimating the installed capital cost, annual operating expense, and the annualized capital charges to determine the total annualized cost for each size spray booth or curing oven. The bases for capital cost estimate are as follows:

- All costs are given in mid-1978 dollars
- Thermal incinerators have 90 percent VOC emission reduction capability with 0.5 second retention time at 649°C
- Catalytic incinerators have 90 percent VOC emission reduction capability at 371°C
- Capital investment includes:
  - -- Basic control equipment
  - -- All materials and labor for complete installation and startup, including foundations, structures, wiring, piping, ducts, etc.
  - -- Contractor's overhead and profit
  - -- Taxes, interest on construction funds, and other indirect costs
  - -- Contingencies of 20 percent

Annual operating expense bases are shown in Table 17. Annualized capital charges are based on a capital recovery factor of 18.67 percent of capital cost, a 10 percent rate, and 12-year equipment life.

INCINERATOR COST ESTIMATES

Costs for incinerators are developed in Table 18 for the various sizes of spray booths and ovens. These costs are based on delivering 90 percent of the emissions to the incinerator and on the bases given previously and in Table 17.

Table 18 includes both thermal and catalytic incinerators with 35 percent primary heat recovery. The addition of heat recovery equipment increases initial capital costs; however, it reduces annual operating expenses through reduced fuel consumption. As can be seen in the table, total annualized cost is increased for catalytic incinerators with primary heat recovery because of the high initial capital costs. Secondary heat recovery (i.e., the use of incinerator heat for other plant processes) is

TABLE 16. SPRAY BOOTH AND DRYING OVEN TYPICAL EXHAUST PARAMETER VALUES

Parameter	Booth or Oven Size		
	Small	Medium	Large
Flowrate, Nm^3/min	425	850	1,274
Temperature, ^oC	21	21	21
LEL, percent	1.3	1.3	1.3
Uncontrolled VOC,[a] Mg/yr	14.8	29.6	44.4
Flowrate, Nm^3/min	85	170	255
Temperature, ^oC	79	79	79
LEL, percent	3.0	3.0	3.0
Uncontrolled VOC,[a] Mg/yr	6.83	13.7	20.5

[a]Based on finishing operations of 8 hr/day for 260 days/yr, or 2,080 hr/yr.

TABLE 17. BASES FOR ANNUAL OPERATING EXPENSE

Item	Item Cost	Cost Bases and Other Comments
Utilities		
Fuel	$104.63/m^3	$101.06/m^3 and $3.57/m^3 for transport and delivery of 27.25 m^3 lots (f.o.b. midwest oil terminal) Fuel properties: No. 2 oil, 0.88 g/cm^3 and 39.3 MJ/m^3
Electricity	$ 0.0242/kWh	EPA-230/3-77-015b report cost for iron and steel industry
Operating Labor	$ 7.20/hr	20 percent for fringe benefits included. One-half hr for each startup or shutdown, one-quarter hr twice each shift for monitoring.
Maintenance		
Labor	$ 7.20/hr	2 x 16 hr for tuneup of combustion equipment and 1 x 8 hr for cleaning of heat exchangers by industrial heating service yearly
Material	$ 7.20/hr	Assumed equal to labor
Special	$ 35.31/(Nm^3/min)	Annual allowance to replace catalyst every third year
Taxes and insurance	2 percent of capital cost	
Administration and permits	2 percent of capital cost	

TABLE 18. INCINERATOR COST ESTIMATES[a]
($\times 10^3$ dollars, mid-1978)

Incinerator Options	Installed Capital Cost	Annual Operating Expense	Annualized Capital Charges	Total Annualized Cost	Cost-Effectiveness ($/Mg)
Small Spray Booth Options:					
Thermal, no heat recovery	182	86	34	120	8.11
Thermal, 35% heat recovery	294	60	55	115	7.77
Catalytic, no heat recovery	125	62	23	85	5.7
Catalytic, 35% heat recovery	258	47	48	95	6.4
Medium Spray Booth Options:					
Thermal, no heat recovery	305	143	57	200	6.76
Thermal, 35% heat recovery	490	100	91	191	6.45
Catalytic, no heat recovery	209	103	39	142	4.80
Catalytic, 35% heat recovery	428	78	80	158	5.34
Large Spray Booth Options:					
Thermal, no heat recovery	364	172	68	240	5.40
Thermal, 35% heat recovery	588	120	110	230	5.18
Catalytic, no heat recovery	250	123	47	170	3.83
Catalytic, 35% heat recovery	517	93	97	190	4.28
Small Curing Oven Options:					
Thermal, no heat recovery	91	43	17	60	8.8
Thermal, 35% heat recovery	142	28	27	55	8.1
Catalytic, no heat recovery	59	29	11	40	5.9
Catalytic, 35% heat recovery	122	22	23	45	6.6
Medium Curing Oven Options:					
Thermal, no heat recovery	150	72	28	100	7.30
Thermal, 35% heat recovery	241	47	45	92	6.7
Catalytic, no heat recovery	98	49	18	67	4.9
Catalytic, 35% heat recovery	205	37	38	75	5.5
Large Curing Oven Options:					
Thermal, no heat recovery	182	86	34	120	5.85
Thermal, 35% heat recovery	284	57	53	110	5.37
Catalytic, no heat recovery	117	58	22	80	3.9
Catalytic, 35% heat recovery	245	44	46	90	4.4

[a]All incinerators operate 8 hr/day, 260 days/yr.

probably not practical since most plants already use the wood waste and dust from sawing and sanding operations as an inexpensive fuel supply.

For thermal incinerators, heat recovery systems initially cost 62 percent more. However, they reduce the annual operating expense by 33 percent. Therefore, thermal incinerators with primary heat recovery result in a 6.4 percent savings in total annualized costs.

Heat recovery systems for catalytic incinerators add 105 percent to initial capital. Annual operating expenses are reduced 25 percent through the use of these systems. The net result is an 11 percent increase in total annualized cost. However, if catalytic incinerators with 35 percent primary heat recovery systems can be operated for 1,214 more hours per year, total annualized cost savings would begin to occur when compared to a catalytic incinerator without heat recovery operating the same number of hours. For single-shift operation, catalytic incineration without heat recovery has the lowest total annualized cost of the four systems considered.

AVERAGE FURNITURE PLANT COSTS

In terms of annualized cost to the average furniture plant, the cost of incinerators for each spray booth and each curing oven would amount to a total plant cost of between $1,000,000 and $6,000,000 depending on the type of incinerator used for each booth or oven and the number of booths and ovens. Table 19 gives average furniture plant costs for small, medium, and large furniture plants using various types of incinerators for small, medium, and large spray booths and curing ovens, respectively. The least costly case is the use of catalytic incinerators with no heat recovery for a small plant, while the most expensive case is for thermal incinerators with no heat recovery for a large plant. All other cases lie between these two. This includes use of mixed incinerator options and sizes in the same plant.

COST-EFFECTIVENESS

Cost-effectiveness of the various incineration options in terms of $/Mg of VOC emissions controlled is given in the last column of Table 19 for each size plant. Cost-effectiveness varies depending on the size of the incinerators used in the various size plants. There is some economy of scale in going from a small spray booth or curing oven to a medium or large spray booth or drying oven incinerator. However, no economy of scale is expected from a manifolded system to a large incinerator due to the previously discussed fire hazard problem with nitrocellulose.

Catalytic incinerators are generally more cost-effective than thermal incinerators. This is indicated in the last column of Table 18. In this table, thermal incineration with heat recovery is shown to be more cost-effective than thermal incineration without heat recovery, while the opposite is true for catalytic incineration. However, this is true only up to a certain number of hours of operation for catalytic incineration. It was shown earlier that at 3,294 hours of operation catalytic incineration with heat recovery becomes more cost-effective than catalytic incineration without heat recovery.

TABLE 19. AVERAGE FURNITURE PLANT COSTS
($\times 10^3$ dollars, mid-1978)

Incinerator Options	Installed Capital Cost	Annual Operating Expense	Annualized Capital Charges	Total Annualized Cost	Cost-Effectiveness ($/Mg)
Small Plant Options: (8 booths, 8 ovens)					
Thermal, no heat recovery	2,184	1,032	408	1,440	8.32
Thermal, 35% heat recovery	3,448	704	656	1,360	7.86
Catalytic, no heat recovery	1,472	728	272	1,000	5.78
Catalytic, 35% heat recovery	3,040	552	568	1,120	6.47
Medium Plant Options: (12 booths, 12 ovens)					
Thermal, no heat recovery	5,460	2,580	1,020	3,600	6.94
Thermal, 35% heat recovery	8,772	1,764	1,632	3,396	6.54
Catalytic, no heat recovery	3,684	1,824	684	2,508	4.83
Catalytic, 35% heat recovery	7,596	1,380	1,416	2,796	5.39
Large Plant Options: (16 booths, 16 ovens)					
Thermal, no heat recovery	8,736	4,128	1,632	5,760	5.55
Thermal, 35% heat recovery	13,952	2,832	2,608	5,440	5.24
Catalytic, no heat recovery	5,872	2,896	1,104	4,000	3.85
Catalytic, 35% heat recovery	12,192	2,192	2,288	4,480	4.32